Changes in perceived contrast of suprathreshold gratings as a function of orientation and spatial frequency

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Abstract—Orientation anisotropy for suprathreshold gratings of different spatial frequencies was measured using a contrast matching procedure. Observers matched the contrast of sine-wave gratings of various orientations to a vertical reference grating set at different reference contrasts. At threshold, the size of the anisotropy increased with spatial frequency, confirming previous results. When the reference grating contrast was set above threshold, the anisotropy declined, and eventually disappeared for gratings of medium spatial frequencies. At higher spatial frequencies, although the relative anisotropy became smaller, it did not disappear within the range of contrasts used in this study. For medium, but not for high spatial frequencies, the data are consistent with Kulikowski's (1976) model of effective contrast constancy.

INTRODUCTION
The orientational anisotropy of human vision is well-documented (Appelle, 1972; Bornstein, 1982). Among adults, the phenomenon is most evident in threshold detection tasks. For example, both resolution acuity and contrast sensitivity are lower for obliquely oriented gratings than for those at the major axes (Campbell et al., 1966, Timney and Muir, 1976). However, the magnitude of the anisotropy varies with the spatial frequency of the stimulus used, the greatest meridional variations being observed at high spatial frequencies (Campbell et al., 1966).

Several studies suggest that performance on threshold tasks may not reliably predict suprathreshold performance. Georgeson and Sullivan (1975) reported that two gratings of different spatial frequency have equal perceived contrast when their suprathreshold physical contrasts are identical. This is in spite of the fact that such gratings have markedly different contrast detection thresholds. They referred to this accelerated gain in the contrast response as contrast constancy. Similar data were obtained by Kulikowski (1976), although the respective authors' interpretations of their results differ.

Georgeson and Sullivan (1975) also described measurements made with astigmatic subjects, whose contrast detection thresholds varied with orientation. They found that in some subjects, the poor sensitivity observed at threshold was maintained at higher grating contrasts. In others, there was no appreciable deficit in performance for matching two gratings of high contrast.

In another study on normal subjects, Essock (1982) obtained magnitude estimates of contrast for gratings of different orientations at different levels of physical contrast. He found that oblique gratings were perceived to be lower in contrast than those falling on

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the vertical and horizontal axes, although for one of the two observers the difference was smaller at higher physical contrasts. No correction for contrast threshold was possible in Essock's (1982) experiment. In another part of the same study, Essock (1982) measured reaction times for gratings of different orientations whose physical contrasts were set at different values above contrast threshold for oblique gratings. He found that there was a reaction time anisotropy which tended to decline as physical contrast increased.

In a more recent study by Camisa and Zemon (1984), a contrast matching procedure, rather than reaction time or magnitude estimation, was used to examine suprathreshold contrast matching. These authors reported a disappearance of orientation anisotropy as grating contrast increased. In a study which examined grating acuity rather than contrast detection, Berkley et al. (1975), found the largest orientation anisotropies for gratings of high physical contrast.

Maffei and Campbell (1970) first reported that the visual evoked potential for oblique gratings was lower in amplitude than for horizontal and vertical ones, and that the difference was maintained over a fairly wide range of stimulus contrasts. Frost and Kaminer (1975) obtained a similar result, as did Yoshida et al. (1983). In a more detailed study, Zemon et al. (1983), reported an evoked potential anisotropy at all values of stimulus contrast. They also noted that at high contrasts the evoked potential anisotropy was greater than that observed psychophysically in the same observers.

In light of these mixed results, it is difficult to make a firm statement on whether or not any form of contrast compensation occurs among observers with normal vision for suprathreshold gratings of different orientations. The present study was designed to resolve some of the apparent discrepancies in the data concerning the magnitude of orientation anisotropies for gratings of various contrasts and spatial frequencies.

**METHOD**

**Observers**
Three practiced psychophysical observers participated in this study. Each had normal visual acuity, and no astigmatism or other ocular abnormalities.

**Test patterns**
Sine-wave gratings were produced conventionally, using a commercially available display generator (Innisfree Picasso) operating under computer control. The gratings were displayed on the face of a Tektronix 608 CRT monitor with a P31 phosphor. Their mean luminance was 20.0 cd/m² and they were visible through a 3-degree circular aperture in the centre of the screen. The observers viewed the patterns from a distance of 118 cm, except for the 20 cyc/deg gratings, when the distance was increased to 175 cm with a corresponding reduction in field size. Head position was maintained using a chinrest.

**Procedure**

**Threshold determination.** Contrast detection thresholds were obtained for gratings of various spatial frequencies presented at each of four orientations, 0, 45, 90, and 135 deg. (Orientations are specified according to ophthalmic convention, where 0 deg = horizontal and orientation values increase with counterclockwise rotation.)

A temporal two-alternative forced choice procedure combined with an interleaved